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SPINAL LOCALIZATION

IN ITS

PRACTICAL RELATIONS.

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PART I.—GENERAL CONSIDERATIONS.

SPINAL localization, particularly in its practical relations to surgical procedure, is one of the topics of the hour which has not yet been fully discussed in any of our Philadelphia medical societies. Although its proportions do not approach those of cerebral localization, the subject has sufficient literature and interest to allow of lengthy treatment and open a wide field of discussion ; but it will be necessary for me to be brief in order to cover the ground.

Spinal trephining is by no means a recent operation ; it has an ancient history both as regards suggestion and actual performance. Horsley* speaks of it as known to surgery since the time of Heister (1757), but Lidell attributes the suggestion to Paulus Ægineta. An operation of M. Louis, performed in 1762, is sometimes referred to as the first instance of spinal resection, but, as stated by Ashhurst and Lidell,† it was not a resection at all, but merely an extracting of some loose fragments of bone on the fifth day in a case of gunshot fracture involving a dorsal vertebra, an operation which was performed twenty-four times during our civil war with satisfactory results.

* *Med.-Chir. Trans.*, vol. lxxi., Lond., 1888, p. 383.
† "Intern. Encycl. Surg.," vol. iv.

Genuine spinal trephining was first performed by Henry Cline, June 16, 1814, for fracture of the twelfth dorsal vertebra. Horsley, writing last year, cites Erichsen as stating that it has been performed in all about thirty times; but Ashhurst, about the same time or earlier, tabulated fifty cases. Of these fifty cases, thirty-three died, seven were not benefited, four were relieved, two recovered, and in four the result was unknown. I have collected fifteen cases in addition to those in Dr. Ashhurst's table, and doubtless a few others have escaped me. In addition to these I have personal knowledge of three other cases in which spinal trephining has been performed, but in which the accounts of the operations have not yet been published.

While we have here, however, a record of sixty-eight cases in which the operation of spinal trephining has been performed, a close study of the details of these cases shows that very few operations were guided strictly by the rules and principles of spinal localization. External pointers, as deformity, depression, or swelling, were commonly present. Gowers and Horsley's case of spinal tumor is perhaps the most brilliant example of localization, and vies with the cases of Macewen and Abbe in brilliancy of result.

Many experimental investigations of the functions of the spinal cord have been performed by Brown-Séquard and a host of physiologists, but the first experiments to determine the exact functions of the horns of the cord at various levels were those of Ferrier and Yeo,* in 1880. Pathological observations had been made prior to this time and have been since, and are largely confirmatory of the results obtained by these investigators. In 1884, Starr† collected most of the work on

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* "Proc. Royal Soc.," No. 212, and *Brain*, July, 1881, vol. iv. p. 223.

† *Am. Journ. Neur. and Psych.*, vols. ii. and iii. p. 443.

this subject up to that date. Ross* has worked in the field of sensory localization to good purpose, contributing an excellent paper on the "Segmental Distribution of Sensory Disorders." Much material of a highly practical character will be found embodied in Gowers's "Manual of Diseases of the Nervous System" and in Seguin's contributions to localization in the "American System of Practical Medicine." Recent valuable papers, partly neurological and partly surgical, on spinal localization are those of Thorburn.† This writer records nineteen cases of injury to the cervical region of the spinal cord, studied with the view of determining the exact spinal localization as indicated by such injuries. He has also contributed a valuable article on injuries of the cauda equina. Osler‡ has published a brief paper on lesions of the conus medullaris and cauda equina, and on the situation of the ano-vesical centre in man. Other papers on allied topics have been contributed by Bernhardt, Oppenheim, and Kirchoff, who are cited by Osler.

It is important to closely study every case of supposed spinal focal lesion, whether from injury or disease. Reports of such cases, particularly when accompanied by autopsies, will continue to be useful until a number of points now obscure become clear; but even without autopsies they may be of great value if minute and accurate. Some of the papers on cerebral localization, most valuable because of their suggestiveness, have been purely clinical and largely speculative; as, for example, some of Hughlings Jackson's and Broadbent's on affections of speech. One of the most instructive articles on spinal localization, that of Remak§ on the localization of the

* *Brain*, January, 1888.

† *Brain*, January, 1887; January, 1888; and October, 1888.

‡ *Med. News*, vol. liii., December 15, 1888.

§ *Arch. f. Psych.*, ix.

lesion in anterior poliomyelitis is based entirely on clinical cases. From a careful study of many cases, Remak shows how various groups of muscles are frequently affected together, and, reasoning back to the lesion, concludes that disease in a certain segment or adjoining segments of the spinal cord will produce paralysis in a group of muscles which act together. He made some highly-interesting observations with reference to palsies of particular muscles or muscular groups. These investigations will be referred to again later in this paper.

NOTES OF CASES OF SPINAL FOCAL LESION, WITH AUTOPSIES.

Let me first refer briefly to a few cases of spinal focal lesion, with autopsies, occurring in my own experience, briefly commenting on them with reference to the possibility of successful operation.

While it has been my fortune to see a large number of patients suffering from intraspinal focal lesions, I have made comparatively few autopsies on such cases. I find among my notes, however, records of six post-mortem examinations, three of which have been reported. Of the six cases, two and perhaps three might have been trephined with some show of success. One of these was an injury in the lower dorsal region in which the lamina of the twelfth dorsal vertebra had been broken and driven inwards, a case similar to one of the operative cases reported by Macewen, similar even to the vertebra injured. A bony mass was present about half an inch long by one-quarter of an inch wide in the external layer of the dura, just at the lower end of the spinal cord. This mass, which was like the bony concretions sometimes found in the falx cerebri, could have been removed by operation, after elevation of the depressed and broken spinal arch.

In another case operation might have been of benefit if performed immediately after the accident. The most important features of this and the first case were as follows: A history of severe injury to the middle and lower spine; this was followed at once by pains in the back and limbs, spinal rigidity, anæsthesia, and paralysis of the lower limbs and of the bladder and bowels. The condition remaining was one of motor paralysis, wasting, contraction, depressed electro-contractility, coldness and lividity, peculiar zones of anæsthesia, and abolition of the tendon reflexes in anæsthetic regions. In this second case, at the upper edge of the twelfth dorsal vertebra adhesions were found which continued down the canal for three or more inches. At the commencement of the cauda equina, which was about the centre of the adhesion, caries of the first lumbar vertebra was found, the portion involved being the inner surface of the laminæ close to the junction of the body. Above and below the caries the adhesions were most persistent. The conus medullaris, cauda equina, and membranes were a glued mass. For an inch or two more above and below this the membrane was considerably thickened, a deposit being present of a calcareous nature.

In a case of caries and dural tumor, of which I exhibit specimens, the patient might perhaps have been benefited by relief of pressure. This patient, a man 72 years old, was admitted to the Philadelphia Hospital with a history that he had been lame in his left leg, the result of a fall, since he was ten years old. No relatives or friends could be found, and, as his mind seemed somewhat clouded, it was difficult to obtain from him any statement of value as to his past condition. It was learned, however, that three or four months before admission he had had an attack in which he suffered from diarrhœa and fever; that he became weak in

both legs, but largely recovered power in them, until four weeks before admission, when he became a complete paraplegic.

He had no paralysis of the face and arms. His left leg was shorter than his right, and was considerably atrophied, measurements showing about an inch difference between the limbs. Motor paralysis was complete in both legs, but he had control over the bowels and bladder. Tactile sensation was diminished in both legs, and on his trunk to a line on a level with the third dorsal spine behind and the fourth rib in front. Pain and temperature sense were preserved. He complained of a belt-like feeling around the waist at the highest level of the anæsthesia. He had a sacro-ischiatic bedsore nearly central in position. He died a few days after admission to the hospital. The brain showed no gross lesion. On opening the spinal canal, when the line of the fourth dorsal vertebra was reached the dura mater was found to be strongly adherent, requiring dissection, and a small tumor or enlargement was attached outside of this membrane on the lateral aspect of the cord. It was about three-quarters of an inch in length and one-third of an inch in thickness. Possibly the cord was slightly diminished in general bulk from compression at this point, but it was not abnormal in consistency, and no hemorrhage nor inflammation were present. The body of the fourth dorsal vertebra throughout was found to be eroded and in a carious condition. For a little distance below the periosteum was detached and the bone partly exposed. The disease of the bone had destroyed nearly the whole of the interior of the body of the vertebra. Below the index-finger could be passed into the cavity, while above was a shell or bridge of bone. The vertebra was not displaced. The intervertebral cartilage between the fourth and fifth dorsal vertebræ was also necrosed. The upper lobe of the right lung

was strongly adherent to the bodies of the third, fourth, and fifth dorsal vertebræ. A communication existed between the space in the decayed vertebra and the pleural sac.

In two cases of syphilomata of the dura mater of the cervical region, operation would have been useless from the nature, extent, and high level of the lesions.

The sixth case was one of hemorrhage into the cauda equina, the symptoms being similar to those in the second case referred to above. The question whether in such a case early trephining at the lowest point of the lumbar region would have been feasible, and would have offered any prospect of relief, will be considered later.

SPINAL OPERATIONS GUIDED BY LOCALIZATION. SPINAL FRACTURES AND DISLOCATIONS.

Trephining the spine in whole or in part, guided by the rules of localization, may be resorted to for fracture, dislocation, tumor (including certain hypertrophic inflammatory pachymeningeal lesions), hemorrhage, abscess, caries, and neuralgia.

Page* has said, with reference to fracture and dislocation, that trephining of the spinal column can be of no advantage; but this is certainly far from being true of the former, and even in some cases of dislocation the operation may be of assistance to the surgeon in bringing about reduction. Other eminent surgeons, as Lidell and Ashhurst, hold that more lives are lost than saved by interference. Whether operation in cases of fracture and dislocation will or will not succeed is largely a question of exact diagnosis of the extent and location of the injuries. When, for instance, it can be demonstrated

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* Heath's "Directory of Surgery," p. 134, quoted by Horsley.

by close study that the brunt of the injury has been borne by the spines and laminæ, operation should be at once performed, and even when in doubt it is better to explore rather than to hesitate in the face of paralysis or death.

An interesting recent successful case is one performed in 1887 by an English surgeon, Mr. Jones, reported by Thorburn in *Brain* for January, 1888, and also later, as to result, in the *British Medical Journal* for October 20, 1888.

The patient, a collier, aged 15, was injured by a heavy stone striking him on the shoulders and back. He received a fracture of his right femur, and was also instantly rendered paraplegic. The limbs presented a position of partial paralysis, with wasting, lost faradic contractility, absent knee-jerk, changed skin reflexes, paralysis of the bladder, cystitis, and priapism. Sensation was blunted or lost over special nerve areas in the lower limbs. The third lumbar spine presented a prominence. To the left and above was another bony prominence. Trephining was performed. The detached spine of the second lumbar vertebra was removed, and showed a gap between the arches of the second and third, filled with dense cicatricial tissue. By means of bone forceps the arch of the second lumbar was now almost entirely removed, exposing the membranes of the cord, which had obviously been compressed by it. Around these membranes was also cicatricial tissue, which was not interfered with. Twenty months after the operation the patient was exhibited at the Manchester Medical Society by Mr. Jones. The condition of the patient was then very satisfactory. Sensation was normal in both legs, which were, however, much wasted, and there was evidence of degeneration in the muscles of the left limb. The movements of the knee-joint were normal, but those of the

ankle were limited to extension, flexion being practically abolished. He had perfect control over his bladder, and could urinate normally. He was able to walk three miles with short intervals for rest. When standing he was obliged to lean on some support unless he bent his knees. He was gradually improving.

An equally interesting, but unsuccessful, case, operated upon by Mr. Hardie, is also reported by Thorburn.* The patient was a man 38 years old. The operation was performed October 26, 1887. The patient had a fall of six feet from a wagon, and immediate paralysis without loss of consciousness followed. He had pain across the shoulders and shooting down the arms to the elbows, and arching backward of the cervical vertebræ. The lower limbs, abdomen, and thorax were absolutely paralyzed. His respiration was diaphragmatic, with sense of dyspnœa and cough. All the muscles of the right upper extremity were paralyzed, and the extrinsic muscles of the right upper limb also paralyzed,—the pectorals, spinati, latissimus. The neck muscles were normal on both sides. The muscles of the left upper extremity escaping paralysis were the biceps, supinatus longus, deltoid, supra-spinatus, and infraspinatus. Both palpebral fissures and pupils were smaller than usual. Anæsthesia extended as high as the third rib in front and the sixth cervical spine behind ; on the right side there was sensation over the region of the deltoid and slightly beyond it, and on the left over the deltoid and down the outer side of the limb to the thumb. No hyperæsthesia was present. Knee-jerk, plantar, cremasteric, gluteal, and epigastric reflexes were absent. The temperature was normal. The urine was retained, the penis turgid. His pulse was 66, with a marked respiratory

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* *Brain*, October, 1888.

wave. A vertical incision about four inches long was made over the cervical spines, with its centre opposite the fifth. The muscles being cleared from the laminæ, an interval of about a quarter of an inch was found between the fifth and sixth spines, and the fifth vertebræ appeared to be slightly displaced forward. The laminæ of the fifth and sixth vertebræ were removed by bone forceps and the dura mater exposed, presenting a perfectly normal appearance without any trace of hemorrhage. The patient died the next day. The heart-beats, which were very feeble and infrequent, continued for about ten minutes after respiration had ceased, but stopped at 3.35. The disk between the fifth and sixth cervical vertebræ was found to be ruptured, the former bone projecting very slightly forward. No fracture was discovered. The dura mater was uninjured, but the cord was flattened opposite the seat of the injury, and was much contused for about an inch above and below, containing hemorrhage in its substance and in the central canal; elsewhere its structure was normal.

In lesions of the cauda equina which cause compression, whether fracture, hemorrhage, or abscess, but particularly fracture, trephining is undoubtedly indicated in most cases, and in some, with our present light, it is imperatively demanded. This view I take from personal experience of cases with autopsies, and of others which I have studied clinically. The same view is strongly taken by Thorburn,* who shows that some of the objections which are valid against trephining higher in the vertebral column, do not apply so fully to injuries of the cauda equina. He advocates trephining in injuries of the cauda equina, always bearing in mind the following conditions:

"1. We must be sure of the localization.

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* *Brain*, January, 1888, p. 406.

"2. We should, if possible, wait for a reasonable period, say six weeks, before operating, and should then do so only if the patient shows no signs of spontaneous recovery.

"3. Should the paralysis of the bladder be early followed by severe cystitis, and should we suspect secondary renal troubles, what are we to do? On the one hand, not to operate probably means death; and on the other, the risk of operation is enormously increased. Further experience may enable us to settle this problem, but at present the outlook appears to be sufficiently gloomy. A third course has suggested itself to me, but I have had no opportunity to test its results,—viz., to drain the bladder by means of a suprapubic cystotomy. The object of draining the bladder is obvious, and the suprapubic appears preferable to the perineal route, because we are thereby enabled to construct our fistula through parts which are not anæsthetic and predisposed to slough. If we could thus prolong life for a time, we might afterwards proceed to operate upon the spinal column with fair hopes of a successful result, and encouraged by the great improvement effected in the case of R. M. C., and the cure obtained in a case recently published by Lauenstein, in which there was complete paralysis of the lower limbs, etc., from a dislocation of the twelfth dorsal vertebra, and where a perfect cure resulted from the removal of the misplaced arches. It would appear, therefore, that whether 'trephining the spine' is or is not justifiable in cases of injury of the cord, it is certainly the proper treatment to pursue in those of the cauda equina, and hence the importance in such cases of making an exact diagnosis."

SPINAL TUMORS.

In most cases of tumor of the spinal cord or its envelopes, operation would not for several reasons be completely successful. It

would, however, be entirely successful in some, and I have come to the conclusion that almost all cases should be trephined for the chance of success, or to relieve pain and diminish the effects of pressure. When the growths spring from the bone or dura mater the chances are, of course, the best.

Even if the neoplasm is situated in front, or surrounds a large part of the cord, trephining might be successful, for during operation the lateral and even the anterior aspects of the cord can be explored, the latter certainly by cutting one or two spinal nerves. This can be seen by examining the cord in position in a fresh specimen. With a little care, using a blunt hook, the cord can be rolled and lifted so as to examine it on almost every side in position. Erosion or caries, with perforation of the body of the vertebræ, can also be determined by careful explorations with properly-curved probes thrust around and beneath the exposed cord.

Three operations for spinal tumor, all of them successful, have been reported by Macewen,* Gowers and Horsley,† and Abbe.‡ The case of Macewen was a boy, 9 years of age. The operation was performed May 9, 1883. The main symptoms were complete sensory and motor paraplegia, with incontinence of urine and fæces. Angular curvature was present, most marked between the fifth and seventh dorsal vertebræ. The laminæ of the fifth, sixth, and seventh dorsal vertebræ were removed. A fibrous neoplasm attached to the theca, between it and the bone, was dissected off. After this, cord pulsations, which had been absent, returned. Twenty-four hours after the removal of the pressure the limbs had lost their livid color and were distinctly warmer; the spastic rigidity had

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* *Lancet*, August 11, 1888.

† *Brit. Med. Journ.*, January 28 and June 16, 1888, and *Med.-Chir. Trans.*, vol. lxxi.

‡ *N. Y. Med. Rec.*, February 9, 1889.

greatly lessened. The sense of tickling had returned to the soles, and that of touch had improved. After eight days the first return of movement was observed; soon after he had perfect control over his sphincters. Six months subsequently he was able to go about without support, and five years afterwards he walked three miles to pay the doctor a visit. He attended school regularly, joined in all the games, including foot-ball, and said he felt quite strong. Charcot has pointed out the occurrence of these connective tissues in cases of caries, and one of the specimens exhibited in connection with this paper is a tumor of this character.

The case of Gowers and Horsley was a man, aged 42 years, and the operation was performed June 9, 1887. He had suffered for three years from localized pain beneath the left scapula. The pain varied considerably. He showed great mental irritability and hypochondria. Four months before operation first the left and then the right leg became weak, and gradually there was complete paraplegia. He had motor and sensory paralysis up to the level of the sixth or seventh dorsal nerves, with intense spasm in the legs, with foot clonus and rectus clonus. Urine was retained and he had some cystitis. He suffered with severe pain around the trunk, which was greater on the left side, and increased to agony by any movement. Caries and syphilitic disease of the spine were excluded. The spines and laminæ of the fifth, fourth, and third dorsal vertebræ were removed, and a fibro-myxoma, about the size of a filbert, was discovered and removed. Mr. Horsley reported, January 4, 1888, that the pain was for a time slightly relieved, but again and again returned with great severity, and the power of motion was only slowly and intermittently regained during the first three or four weeks. The local pain gradually diminished and motor power grad-

ually returned. The surgical result was excellent. He reported, June 12, 1888, that the patient had lost the agonizing pain, and at the same time gradually recovered motor and sensory power, as well as the control of the bladder and rectum. He remains in perfect health.

One of the most recent contributions to the subject of spinal trephining, that of Dr. Robert Abbe,* is a case of extradural tumor of the spine, with complete paraplegia, in which the operation resulted in recovery. The patient was a young man, aged 22 years, and the operation was performed on May 26, 1888. The first symptom was pain in the back; swelling of the soft parts two inches wide by three long. There was disturbance of tactile sensibility in both legs, followed by gradually-increasing paresis. The line of hyperæsthesia was between the anæsthesia and the normal skin. He had uncontrollable twitching of the legs, which were cyanotic when dependent. The spine became rigid and very painful; the hyperæsthesia, anæsthesia, and paralysis deepened. He suffered with girdle pains about the limiting line of the disease. He had incontinence of urine and fæces. Active hectic was present. The spines and laminæ of the eighth, ninth, and tenth vertebræ were cut away, and a dense mass of tissue and desiccated pus was removed by scraping. Sensation began to return on the eighth day; in the fourth week he began to move his left leg and toes on the right. The fever and pain disappeared, and in six weeks he moved both legs. He improved continuously, and in four and a half months he moved, pushing a chair. He was exhibited to the Surgical Society of New York eight months after the operation, when he walked well without support and was stout and heavy.

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* *N. Y. Med. Journ.*, November 24, 1888, and *N. Y. Med. Rec.*, February 9, 1889.

In the disease described by Charcot and Jeffroy as hypertrophic internal pachymeningitis, operation for the removal of the lesion might in some cases prove successful. Usually after the disease has existed some time the lesion becomes practically a fusiform tumor of considerable size. It might be objected, perhaps, that the disease is inflammatory in character ; but, on the other hand, it is chronic, often of slow development, and sometimes almost stationary. No harm could result in a disease always one of great suffering and eventually fatal, and great relief and possibly a cure might sometimes be effected.

INTRASPINAL HEMORRHAGE.

As within the cranium, so within the spinal canal, hemorrhage may be of four varieties as to location,—namely, (1) supradural or extrameningeal ; (2) subdural ; (3) subarachnoid or subspinal ; and (4) intraspinal,—that is, into the spinal cord itself. The hemorrhage may be posterior, anterior or lateral, or antero-lateral, postero-lateral, etc. ; but commonly it will surround the cord ; if intraspinal, it may be into the anterior or posterior horns, the central gray matter, or columns, but usually it will be diffused through the cord. With reference to the question of trephining it is only practical to consider supradural or subdural hemorrhage.

A net-work of large blood-vessels lies between the dura mater and spinal bone, and from this supradural spinal hemorrhage usually occurs. Such an extravasation may be minute, of moderate size, or very extensive. The symptoms of supradural hemorrhage will vary, of course, with its location and extent. The history is generally of a sudden attack, often after a fall or exhibition of violence of some kind.

Hemorrhage between the dura mater and the bone probably usually finds its way down

the whole length of the spinal canal to the beginning of the sacral canal. The space surrounding the cauda equina in the lumbar canal is comparatively large, and the much-narrowed sacral canal is placed at a slightly different level, so that much of the effused blood would probably accumulate in the lumbar region. The fat and connective tissue between the theca and the bone are loosely distributed in the extradural space, and differ considerably in amount in different individuals, so that in some cases more than others much of the blood would be entangled and coagulated in the meshes of the connective tissue and fat near the seat of extravasation. The subdural space, although much smaller than that outside of the dura, is a smooth serous cavity, and therefore much of a hemorrhage at any level would also probably descend into the region of the conus and cauda equina.

I do not know of any reported case in which trephining has been resorted to simply for the relief of intraspinal hemorrhage. In a case of resection at the Bellevue Hospital, New York, by Dr. Stephen Smith,* it is reported that notwithstanding from eight to twelve ounces of extravasated blood, having a dark color, escaped from the spinal canal after the depressed bone had been extracted, the compression of the cord from extravasated blood and the paraplegia steadily crept upward, and finally caused death by asphyxia. The case is reported to show that the operation of trephining the spinal column or resecting the vertebræ would not relieve the spinal cord from compression when it was exerted by the extravasation of blood.

The diagnostic symptoms of meningeal hemorrhage as given by Gowers and others, and according to my own experience, are as

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* Lidell, in the "Intern. Encycl. Surg.," vol. iv. p. 379.

follows: (1) sudden and violent pain in the back, less or more diffused; (2) pain along the course of the nerves passing through the membrane near the extravasation; (3) abnormal sensations,—tingling, etc., and hyperæsthesia, referred to the same parts; (4) spasm involving vertebral and other muscles supplied by affected nerves and also sometimes the muscles supplied by the cord below the seat of the hemorrhage; (5) sometimes general convulsive movements; (6) sometimes spasmodic retention of the urine; (7) consecutive paralytic symptoms, but not usually complete paralysis.

Some points of differential diagnosis between meningeal hemorrhage and extravasation into the substance of the cord should be borne in mind. Symptoms of irritation, such as pain, hyperæsthesia, paræsthesia, and spasm, in meningeal hemorrhage are usually immediate or very early, and may precede paralysis, which is commonly not complete. In hemorrhage into the substance of the cord paralysis may be very complete at first, or rapidly become so, and symptoms of irritation may be very largely wanting. Hemorrhage may, and not infrequently does, involve not only the membranes but also the substances of the cord, giving complex symptoms.

In some cases of intraspinal hemorrhage, whether primary or secondary, trephining might be performed in two places in order to make sure of a good result,—namely, at the supposed seat of the extravasation, and at the lowest portion of the lumbar spine, where, as already indicated, much of the extravasated blood would gravitate. Kronlein, it will be remembered, has recommended that in cases of cranial meningeal hemorrhage, two trephinings should be performed if one is not successful, and several cases of failure in trephining for intracranial hemorrhage have been reported, which would have been successful

had the second operation been performed. In like manner, two trephinings of the spine, or a single trephining at the lowest possible place in the lumbar region, might prove successful where failure would otherwise result.

The somewhat frequent occurrence of spinal hemorrhage, with fracture of either the body, spines, or laminæ of the vertebræ, must not be overlooked. The diagnosis of the exact height of the lesion and the decision as to trephining may often have to be settled negatively or positively through a consideration of the question of the probability of a double lesion in cases of accident,—namely, both fracture and hemorrhage. The fracture and the hemorrhage may be situated at different levels, or if the hemorrhage occurs primarily at the seat of the fracture it may find its way down the canal.

I might give many illustrations gathered from medical and surgical literature of intraspinal hemorrhage in which operation would probably have proved successful, but I will confine myself to two, one twenty years old and the other a recent case.

Jackson* reported an interesting case of localized spinal apoplexy, which with our present lights might perhaps have been relieved and a life saved by careful trephining. The patient was a bright girl, 14 years old. While dressing her fingers felt weak. The next day she had a similar weak feeling in her hands. One day later she was unable to move her arms except at the wrists. Later, the intercostal muscles did not act quite freely, and she seemed to lie heavier in the bed. Moist crepitant râles, with a little cough, developed. On the fifth day after the first symptoms, careful examination clearly demonstrated great loss of power in all the voluntary muscles of respiration and in those muscles of the arm, back, and chest supplied by the

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* *Lancet*, July 3, 1869.

cervical nerves. The diaphragm became fixed, and there was slight lividity about the cheeks, with a fall in the natural temperature. Sir W. Jenner, who was called in consultation, diagnosticated a clot in the cervical portion of the spinal cord. Death soon took place without pain. The whole cervical portion of the spine, but particularly in front and to the left, was embedded in an oblong clot of dark venous blood outside the membranes. The clot ceased at the seventh cervical vertebra.

In this case, as the reporter remarked, the effusion probably took place very gradually, had room to extend itself, and coagulated very slowly and imperfectly. Until the phrenic nerves were interfered with nearly every symptom might have been attributed to hysteria.

The following case was reported by Dr. Arlidge to the Staffordshire branch of the British Medical Association.* The patient, 44 years old, a drinking man, was admitted to the infirmary with complete motor paralysis of the legs, and some weakness in the arms, where, too, formication and numbness were experienced. Sensation was normal, and the legs were painless and their reflexes abolished. His only complaint was of dorsal pain. The bladder was distended, and prior to admission had been emptied by the catheter, but there was no dribbling of urine. Some rhonchi were noted in the upper part of the left lung; heart healthy; bowels confined for four days; the cerebrum undisturbed. The first temperature taken was 103.6°, but the next day it fluctuated between 105° and 106°, and rose to 107.4° the day preceding his death, on September 26, and was accompanied by some delirium. A post-mortem examination revealed a copious hemorrhage

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* *Med. and Surg. Rep.*, March 23, 1889, vol. lx. No. 12, p. 370.

within the meninges of the spinal cord, extending downward from the last cervical vertebra for about six inches. The blood was coagulated. No ruptured vessels were found in the cord itself, and no cerebral disease, although the dura mater was very adherent to the skull. There was no fracture of the spine, and no caries of any vertebra.

CARIES AND ANGULAR CURVATURE.

The question of operation for the relief of angular curvature of the spine is one of considerable importance and not to be dismissed hastily. Such an operation has been, until lately, commonly regarded as useless or worse. Its dangers have been overrated, although they are doubtless greater somewhat than most cranial operations. Macewen has reported an extraordinary series of six cases, in which elevation of the posterior laminæ of the vertebræ was performed,—in four with recovery. In favor of operation are,—(1) the fact that by thus allowing the cord to expand backward a present serious paralysis may sometimes be relieved without imperilling the ordinary chances of recovery by anchylosis; (2) when an approximate cure has been effected by anchylosis, but a paralysis or contractures remain, the latter may sometimes be relieved and improved; (3) secondary degeneration of the cord may sometimes be prevented or arrested; (4) when the paraplegia is produced by the connective tissue or other tumors which sometimes accompany angular curvature, rather than by the latter, such growths can be removed. Against operation are,—(1) that cases can sometimes be cured without such heroic procedure; (2) that caries often involve the body of so many vertebræ that operation is often useless or worse.

Trephining in such cases has been performed twice at the Philadelphia Hospital by Dr. White in cases of Dr. Dercum.

A case is reported by Mr. G. A. Wright,* of a boy, 7 years old, who was operated upon January 26, 1888. Disease of the spine was observed one month before operation, with marked angular curvature in the mid-dorsal region, with some lateral thickening. Paresis of the lower limbs was present, and the patient grew gradually worse. Before the operation he had complete paralysis of both lower extremities, with incontinence of urine and fæces. Anæsthesia to the level of the eleventh rib on the right side, and on the left decrease and finally loss of sensation, developed, the anæsthesia extending from the toes to the level of the pubes; from thence to the line of the eleventh rib a condition of analgesia existed. The muscles of the lower limb were in a state of tonic contraction, with marked flexion. The plantar reflexes were exaggerated; cremasteric very feeble, and deep reflexes could not be obtained. His feet were slightly swollen and cyanotic. Until late the symptoms were more marked on the right side than on the left. External and internal treatment were used without avail. Three laminæ were removed in the dorsal region. The theca of the spinal cord exposed was surrounded by a buff-colored, tough, leathery substance, which was cut away with the scissors. The cord did not appear to pulsate, but no point of constriction could be found. Some improvement took place in voluntary motion and sensation during a month following the operation. Later, the area of anæsthesia increased, and the condition of the patient became about the same as it was before operation.

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* *Lancet*, July 14, 1888.

SPINAL ABSCESS.

Spinal abscess, like brain abscess, is usually a complication found in connection with disease of the bodies of the vertebræ, and localization rules will not commonly be of much value in making a diagnosis. Pus at any level within the spinal canal will, like blood, usually find its way to the lumbar region. In rare cases suppuration is confined to the space between the dura mater and bone, and when our diagnostic acumen becomes greater we will doubtless in some of these cases be able to trephine with advantage to our patient. Pachymeningitis, with or without suppuration, is generally due to traumatism or vertebral caries, but occasionally cases appear to arise as primary or idiopathic.

In this so-called idiopathic suppuration in the spinal dura mater, trephining low down to give exit to the pus might in rare cases prove a useful procedure. Such a case is that reported by Dr. Robert Maguire.* Other cases have been reported by Mueller, Spencer,† and others.

In Spencer's case of idiopathic inflammation of the spinal dura mater, the patient's illness began with pain in the feet and knees and in the small of the back, frequently shooting down the back to the legs. He had fever and diarrhœa. There was great tenderness on pressure over both lumbar regions. The surface of the body was covered with copious acid sweats. Temperature elevated; pulse rapid, wiry, regular; tongue dry, white fur in the centre, red at the tip and edges. Breathing became rapid and somewhat painful, with a dry, hacking cough. The patient became delirious and

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* *Lancet*, July 7, 1888.

† Ibid., June 14, 1879.

his pain in the back very severe, but no paralysis until late. The neck was very stiff. There was a peculiar purplish mottling on the chest and abdomen. He became steadily weaker and died. The whole spinal canal was filled, from within two or three inches of the head down to the sacrum, with thick, creamy pus of a light yellow color and containing numerous shreds of lymph. The pus was found to lie outside the dura mater, between it and the periosteum. The pus had found its way out of the canal through the intervertebral foramina, and surrounded the spinal nerves for some distance. It had also passed out through the laminæ and infiltrated the connective tissue between the muscular structures on each side of the spine, forming collections of various sizes, the largest opposite the lumbar vertebræ. These were not abscesses, but infiltrations of pus into the interstices between the muscles. The tissues around these collections of pus were softened and the spinal nerves were laid bare. The most noteworthy of these collections was one opposite, and to the right of, the sixth and seventh dorsal vertebræ; the pus had here found its way under the costal pleura and projected into the thorax as a tumor, the size of a large hen's egg, lying close to the spine. In this case trephining low down as well as operations in the external abscesses might have been performed.

NEURALGIA.

In rare cases of intractable neuralgia trephining and section of the nerves close to the spinal cord may be tried as a last resort. This operation has been performed in one case by Dr. Abbe,* of New York, on the recommendation of Dr. C. L. Dana. The patient, a man 44 years old, was operated on Decem-

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* *N. Y. Med. Rec.*, February 9, 1889.

ber 31, 1888, and January 2, 1889. His symptoms began with throbbing pain on the posterior surface of the right forearm above the middle; later, paroxysmal pain, giving a peculiar twitching sensation in the thumb, index, and middle finger; after some months there was complete disablement of the hand, which he kept in a stiff position with the fingers semiflexed. The forearm and hand were slightly emaciated, with atrophy of the muscles in the interosseous spaces. The posterior, interosseous, and ulnar nerves were stretched without any improvement. The arm was amputated about the humeral insertion of the deltoid, but without abatement of pain. The morphine habit had been contracted. He had twitchings and tonic contractions of the muscles of the trunk; also the Brauch-Romberg symptoms; he swayed in standing and had a tendency to fall to the right. Knee-jerks were exaggerated, and there was ankle clonus in the right leg. The right shoulder showed muscular atrophy, and stiffness in the neck muscles. A small tender neuroma of the muscular nerve was removed without relief. The right half of the laminæ of the third cervical to the first dorsal spine was removed. Both motor and sensory roots of the sixth and seventh cervical nerves were cut square across outside of the dura. The posterior roots of the seventh and eighth cervical nerves were cut off close to the posterior columns. The patient made great improvement.

PART II.—THE FACTS AND RULES OF SPINAL LOCALIZATION.

In a paper on "Cerebral Localization,"* I directed attention to the possibility of six classes of symptoms presenting themselves for the consideration of the neurological diagnostician,—namely, those of (1) local irritation, (2) local destruction, (3) local pressure, (4) invasion by lesions growing from adjacent areas to those under determination, (5) local instability, (6) reflex action at a distance. All or any one of these classes might require to be considered in localizing a spinal lesion, but the last three are not relatively of as much importance in spinal as in encephalic diagnosis; and, in order to restrict the present paper to reasonable limits, the discussion of this part of the subject will practically include only a study of symptoms of irritation, destruction, and pressure. Irritative, destructive, and compression lesions, whether intracranial or intraspinal, give rise mainly to three great classes of diagnostic phenomena,—reflex, sensory, and motor. Vaso-motor, trophic, visceral, thermic, psychic, and some special symptoms, have at times considerable importance, but are generally secondary in value for ordinary practical purposes to the three classes mentioned.

Under reflex phenomena are usually included the cutaneous reflexes,—scapular, epigastric, abdominal, cremasteric, gluteal, plantar, etc.; and the so-called tendon reflexes,—wrist-jerk, knee-jerk, ankle-jerk, ankle-clonus, perineal-jerk, etc. Under the same head also come such phenomena as the involuntary reactions of the rectum, bladder, and sexual organs. Reflex symptoms may be, as might

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* *Transactions of the Congress of American Physicians and Surgeons*, First Triennial Session, Washington, p. 238, 1888.

be expected from the functions of the spinal cord, of decided localizing value in spinal lesions, whereas for brain lesions they are usually only of general significance and value. Such reflexes as the scapular, epigastric, abdominal, cremasteric, gluteal, plantar, and rectal may, for instance, greatly help to fix the height of a lesion, as may also such phenomena as knee-jerk, muscle-jerk, and ankle-clonus, but the latter are sometimes in spinal as in cerebral cases only of general significance.

Some of the so-called reflexes are a guide to definite spinal segments. While, however, it is important and a great aid to prompt diagnosis to recognize quickly certain marked isolated symptoms, as disturbance of particular reflexes, on the other hand it is essential that such phenomena should not be misinterpreted. Exaggeration of certain reflexes, as, for instance, the ankle-jerk, knee-jerk, the cremasteric-jerk, etc., indicates not merely disease producing irritability of the centres for these phenomena, but, it may be, rather disease or compression in the cerebro-spinal axis anywhere above these centres. Abolished knee-jerk may be indicative of extensive degenerative disease of the spinal cord, as in posterior sclerosis; or, it may, in much rarer cases, indicate limited disease of the particular segment of the cord related to the patellar tendon. Westphal,* for instance, has reported the autopsy of a case of dementia paralytica, in which the patellar reflex had been absent on the left side only; and in which sections of the cord showed extensive sclerosis of the posterior root-zones at the junction of the lumbar and dorsal regions on the left side, while on the right was only a slight beginning of the sclerotic process.

Under sensory phenomena it is necessary to consider clearly the particular variety of sensation lost or perverted, the exact cuta-

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* "Ann. Univ. Med. Sci.," vol. i. p. 95, 1888.

neous areas affected by increase, depression, or perversion of sensation, the nerves involved, the situation of their nuclei in the cord, and the relations of their origin to the intervertebral foramina. These sensory phenomena include the symptoms,—pain, hyperæsthesia, anæsthesia, and paræsthesia.

The great motor symptoms are paresis or paralysis, spasm, contracture, and tremor. In studying motor phenomena, we must consider not only the muscles affected by loss or exaltation of power, the exact nerve-supply to such muscles, and the intraspinal course of these nerves, but also the situation of the nuclei of these nerves in certain segments of the spinal cord, and even the particular cell-groups to which such nuclei belong. The value of a study in spinal localization depends largely upon the *exactness* with which we differentiate such phenomena and relate them to their lesions.

A good practical point is the importance of some single striking fact in spinal function in localization diagnosis for surgical or other purposes. That the phrenic or diaphragmatic spinal centre is situated in the fourth, or in the third and fourth cervical segments, should, for instance, be taken into full consideration in operations in this locality, great care being taken not to bruise or deeply injure the cord, or to explore with needles or by incision a region where such a vital centre has its abiding-place. Respiratory and cardiac phenomena occur with lesions at and above the phrenic centre; pupillary changes when the cord is affected above the level of the second dorsal nerve or segment; while extreme trophic or vaso-motor affections of the skin and its appendages are only present when the central gray matter, somewhat posterior to the central canal, is diseased.

My main object in this portion of the present paper is to give the methods of referring or relating sensory, motor, reflex, and other

phenomena, which are distributed in limited regions of the body, to the particular levels of the spinal cord in which they have their source or termination. It is necessary, for both the physician and surgeon, to have quick and ready methods of determining the position of a lesion in the spinal cord by a study of the symptoms presented. The study is a broad one, and, in considering it, a paper might be almost indefinitely extended ; it is necessary, therefore, to seize upon salient features and methods of presentation.

SOME POINTS IN COARSE SPINAL ANATOMY.

Certain well-known anatomical facts should always be borne in mind when considering for practical purposes the question of spinal localization. We should remember that the spinal cord proper is only from seventeen to eighteen inches long, while the spinal canal to the last lumbar vertebra is about twenty-three inches, and, if the sacral portion and coccyx are included, four inches more should be added. The cord, therefore, is much shorter than the canal, and usually reaches only to about the second lumbar vertebra. As already indicated in Part I., one of the most important and most available positions for successful spinal surgery, in cases of localized lesion, is the region of the cauda equina, most of which is entirely below the spinal cord. We have, in other words, a comparatively extensive intraspinal region in which the lesions are, strictly speaking, peripheral, and the diagnosis, both local and general, must be made with this fact fully recognized. That the spinal cord does not fill its canal transversely is also a familiar fact, the significance of which should also always be before us. The cord is, indeed, suspended very loosely in the canal. It follows, therefore, that many of the intraspinal lesions which are operable are membranous or bony in origin, and in symptomatology are,

in part, at least, peripheral, as they involve nerve-trunks in their intraspinal course, however long or short this may be. Every one who wishes to become practically familiar with spinal anatomy for surgical purposes should study a series of transverse sections showing the relations of the spinal cord to its enclosing envelopes, membranous and bony. Even the dural sheath is much larger than is necessary for its contents. I have already referred to the fact growing out of such anatomical studies of the spine, that the spinal cord can be lifted with care so as to be the subject of operation on any of its surfaces, anterior or lateral, as well as posterior. A consideration of all the questions relating to the spinal membranes and spaces will eventually enable us to separate with fair accuracy the lesions which are supradural, subdural, and strictly speaking spinal.

For various reasons, operations for localized lesions, next to the cauda equinal region, probably offer more chances of success in the dorsal spine than elsewhere, owing to the less size of the cord and the less danger in operating. In the cervical and lumbar enlargements the greater bulk of the cord and the closeness of the nerve-roots is always to be considered. From one part of the cord, the smallest in transverse section, some of the largest nerves of the body originate. This is the narrowed lowest extremity of the cord, the conus medullaris, in which the lower sacral nerves have their roots. It is a region small in general bulk, because, owing to its position, it contains few conducting tracts, although relatively a large amount of gray matter. Lesions of this conus medullaris, embedded in its net-work of great nerves, can be accurately made out by symptoms, and its actual and relative size to the membranes and spaces of the spine should therefore always be kept in view.

The intraspinal course of the spinal nerves

should be absolutely familiar. Nearly all of the nerve-roots descend to the foramina, from which they emerge to be distributed to various parts of the body. The lowest nerves have, of course, the longest intramural course. Some facts about the relations of spinal segments to the vertebræ, foramina, and nerves are, doubtless, known to all, but are probably not much considered. The segmental nature of the spinal cord will be referred to presently at some length. The term spinal segment is used to indicate the limited vertical portion of the cord from which arises each pair of spinal nerves. In the cervical region are eight of these segments, but only seven vertebræ ; hence the eight pair of spinal nerves emerge from their foramina in such a manner that, although they all descend a little in their course, they emerge after the first, so that the segments are located opposite spines and bodies of the vertebræ which do not correspond in name. The third cervical segment, for example, according to Gowers, is about opposite the first cervical spine, and its nerves emerge between the second and third cervical bodies. The eighth cervical segment is about opposite the sixth cervical spine, or the junction of the sixth and seventh, and its nerves emerge between the seventh cervical and first dorsal body. In the dorsal region the segments are the longest of the entire cord, and they are not situated numerically opposite the spines and bodies of the same name in any single case. The first dorsal segment is nearly opposite the seventh cervical spine and body; the second dorsal nearly in a line with the first dorsal spine and body. The tenth, eleventh, and twelfth dorsal segments are much shorter than the segments from the first to the ninth, and these three segments are included chiefly between the eighth and tenth dorsal spines and bodies. The entire eleven spinal segments, from the first lumbar to the coccygeal, inclusive, are

crowded vertically between the eleventh dorsal and second lumbar spines and bodies, a space of only about two to three inches.

Commonly, we speak only of two sets of nerve-roots,—the anterior or motor, and the posterior or sensory,—the great discovery of Sir Charles Bell. Bell, however, really divided the nerve-roots throughout the central nervous system into three sets, the third being a lateral or respiratory set, and containing nerves which excite motions which depend on or are related to the act of respiration. Gaskell* says that physiologists have failed to follow this because the triple arrangement of these nerve-roots was not immediately evident, like the separation of the anterior and posterior roots. This lateral tract of nerve-roots is the same as the non-ganglionated part of the splanchnic root.

These lateral roots do not concern us much with our present lights in determining questions of localization. When, however, visceral and vascular localization have been more perfected, the question of the existence and involvement of these lateral groups will receive greater attention. Every segment of the spinal cord, according to Gaskell, gives origin to two roots, a somatic and a splanchnic,—the latter being the roots of the nerves supplied to the viscera and blood-vessels; the former to the muscles, skin, and tissues other than those which are vascular and visceral. The somatic roots are, in other words, the motor and sensory, or the anterior and posterior roots, and in the main are connected respectively with the cells of the anterior and posterior cornua. The lateral roots arise from two columns of nerve-cells,—namely, the column of Clarke and a column in the lateral horn. The splanchnic root arising from the column of Clarke is ganglionated, while that arising from the lateral horn is

* *Jour. Physiol.*, vii. 1–80. London, 1886.

non-ganglionated; and the nerves corresponding to the latter go to muscular tissues chiefly. Lesions of these nerve-roots, or of the cell-groups or columns of the cord, with which they are connected, give rise chiefly to vaso-motor, trophic, secretory, and visceral phenomena, distributed in accordance with the segment of the cord or the special pair of nerve-roots implicated. These lateral roots are found in greatest number in the region from the second thoracic or dorsal segment to the first lumbar.

SEGMENTAL CHARACTER OF THE SPINAL CORD.

One of the first steps towards an understanding of spinal localization is the full recognition of the segmental character of the spinal cord. It is to be regarded not as a single organ, but as a series or succession of organs vertically linked together,—a chain of segments one placed above another. In many of the lower animals, as in fishes and snakes, this arrangement is obvious, the spinal cord being made up of a series of alternating swellings and constrictions. "Each segment," says Bramwell,* "may be viewed as a distinct spinal unit, or, to speak somewhat figuratively, as a distinct spinal cord for a definite area of the body,—viz., that portion of muscle (muscular area) to which its anterior roots proceed, and that portion of skin, tendon, muscle, mucous membrane, viscus, etc. (sensitive area), to which the fibres of its posterior nerve-roots are distributed. Now, the essence of the clinical examination of the spinal cord consists in the separate and systematic examination of each spinal segment by observing the motor, sensory, reflex, vasomotor, and trophic conditions of the body area." According to Professor Hill,† of Cam-

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* "Diseases of the Spinal Cord," p. 1. Edinburgh, 1884.
† *Brain*, January, 1888.

bridge, the recognition of the segmental succession in the arrangement of the nuclei of the nerves of the spinal cord is due to the late Professor Aeby. In the Hunterian Lectures, in 1885, Hill applied this principle of segmentation to the brain, or, at least, to the cranial nerves, attempting to fix the position in the cerebral axis of the nuclei of these nerves by a consideration of their segmental distribution in the head.

LOCALIZING PHENOMENA REFERABLE TO THE CONDUCTING TRACTS IN THE SPINAL CORD.

The spinal cord of man, besides being a great centre, or collection of centres, includes also a conducting medium, through which the great tracts (motor, sensory, etc.) pass, to connect the brain with all the segments situated below, and these segments with each other. In man, the conducting tracts may be regarded as developmental additions to the original spinal segment. It is in its capacity as a centre—in the capacity of each segment as a special centre—that we are particularly concerned in studying spinal localization, but the symptoms produced by irritation, destruction, or compression of the conducting tracts will often greatly modify an opinion as to the exact height, and particularly the extent of a lesion. I cannot, of course, go into a lengthy consideration of the functions of the white substance of the cord. This can be found in the treatise of Gowers, or any good work on nervous diseases. For completeness, however, I will summarize the subdivisions of the cord and their functions, and make some practical applications to the subject of localization, in the main following Gowers in giving the functions of the different subdivisions. A transverse section of the cord at different heights would give a somewhat but not greatly differing appearance. In a portion of the cervical region the greatest

number of subdivisions are present. Starting here with the posterior median portion of the cord,—the part which would be first exposed by the surgeon's knife and saw,—the posterior column is divided into two parts,—the *column of Goll*, or *postero-median column*, and the *column of Burdach*, also known as the *postero-external column*, or *posterior root-zone*. The column of Goll in all probability conducts tactile impressions. The column of Burdach, containing, as it does, the posterior root-fibres, has for its function the conveyance of sensory impressions inward through these root-fibres, and probably also for short distances it carries these sensory impressions vertically. Just external to the periphery of the posterior horn begins a most important conducting tract,—*the pyramidal tract*, or, as it is usually called, *the lateral or crossed pyramidal tract*,—which occupies the posterior half of the lateral column outside of the posterior horn. Its function is unquestionably chiefly motor conduction, particularly from the brain to the parts below the arm. A column, shallow from without inward, but wide circumferentially, is the *direct cerebellar tract*, which lies chiefly between the lateral pyramidal tract and the periphery of the cord. Flechsig believes that this column conducts impressions from the muscles of the trunk. When diseased it degenerates upward, and therefore its function must be to conduct upward. It is probably connected with Clarke's vesicular column, and therefore with visceral and vascular sensibility and control. Between the pyramidal tract and the concavity formed by the junction externally of the anterior and posterior horns is a comparatively narrow space called *the lateral limiting layer*, whose fibres may connect the gray matter at the different levels. What Gowers has termed the *antero-lateral ascending tract* occupies about the same position in the antero-lateral columns as the direct

cerebellar tract does in the postero-lateral column. Its function is believed by Gowers to be the conduction of the sensations of pain and temperature. In disease it certainly degenerates upward, and therefore must in health conduct upward. Journeying still towards the front of the cord and the median line, we find that the antero-lateral white substance is very largely occupied by what is now called the *column of the anterior ground-fibres*, a name given by Flechsig. The anterior root-fibres traverse it, and its function is probably also to connect the anterior horns at different levels, and through the anterior commissure the anterior horns of the two sides of the cord at the same or at different levels. Like the posterior root-zone, the ground-fibres of this column do not degenerate through any considerable vertical length of the cord. Lastly, the *anterior pyramidal tract, or column of Türck*, is a narrow tract lying close to the anterior median fissure, sometimes varying in form and size, and having for its function the conduction of motor impressions from the brain to the arm. If this is its function its fibres must cross in the cord.

It is evident from this brief statement of the subdivisions of the white substance of the cord that, by closely bearing them in mind, the diagnostician will be greatly helped in locating the horizontal as well as the vertical position of a focal lesion, compressive or destructive, or both. Such a consideration may enable us to say, for instance, whether such a lesion is anterior, posterior, or lateral, or how much it occupies any one or more of these positions; or, finally,—a matter of great importance, as pointed out by Horsley,—the mode of extension of a unilateral lesion, by a tumor which eventually becomes bilateral.

One of the oldest, and, at the same time, one of the best, illustrations of the importance

of bearing in mind the functions of the various columns or tracts of the cord is afforded by the affections known as spinal hemiplegia and spinal hemi-paraplegia, which are due to focal lesions confined to a lateral half of the spinal cord. In the first place, such a lateral lesion is modified by its height in the cord. If comparatively high up in the cervical region and completely unilateral, the patient would exhibit motor paralysis of both the arm and the leg on the side of the body corresponding to the seat of the lesion, because of the implication of the column of Türck or direct cerebral tract, and the lateral or crossed pyramidal tract, which both decussate above the lesion. Sensation would be affected chiefly on the side of the body opposite to the seat of the lesion, because of the involvement of the antero-lateral ascending tract and the column of Goll, and because also the sensory tracts decussate in the cord itself. From involvement of the direct cerebellar column, vaso-motor and visceral symptoms would be present, chiefly on the same side as the lesion. The temperature is sometimes higher, for instance, on this side. The pupil may be affected through the cilio-spinal centres. This is simply the gross, sketchy picture of a lesion high up in the cord. The phenomena would vary considerably according as the lesion was chiefly compressive, irritative, or destructive.

A unilateral focal lesion of the dorsal cord would give hemi-paraplegia. In such a case the arm, the pupil, and the neck escape. Motor paralysis occurs in the leg of the same side, and anæsthesia in the trunk and leg of the opposite side. Sometimes a band of hyperæsthesia, or even wide-spread hyperæsthesia, is present on the side of the lesion, due doubtless usually to irritation of nerve-roots.

Instead of this somewhat complete symptom-picture, we may have a set of symptoms which are dependent upon involvement of

only one or two of the subdivisions of the white substance of the cord, although such exceedingly circumscribed lesions are comparatively rare. By the close study of history and symptoms we can sometimes trace the progress of a lesion from one tract to another.

Some peculiarities in sensory symptoms may occasionally give the clue to the possible extent of a lesion. The loss of the tactile sense, with the preservation of the senses of pain and temperature, for example, mentioned in one of the cases in the first part of this paper, was possibly of some value in connection with the question of the localization of the spinal paths for the transmission of the sensations of touch, pain, and temperature. Schiff's and Gowers's view, as stated, is that the lateral columns contain the tracts for sensibility to pain and probably also to temperature, and the posterior columns the paths for the conduction of tactile sensibility. In a case of focal lesion with compression, like the one reported, the existence of tactile anæsthesia, without loss of sensation of pain and temperature, would seem to be most easily explained on the supposition that the paths for these different sensations are not in exactly the same position in the cord. The columns for touch being the most posterior, the tactile anæsthesia may have been due to counter-pressure from jamming backward of the cord by the vertebral displacement.

Let me say a few words about the vertical extension of the spinal conducting tracts. The column of Goll, or postero-median column, extends throughout the whole length of the cord. The postero-external column, or column of Burdach, posterior root-zone of Charcot, continues throughout the entire cord, but degenerates only a short distance above a lesion. The direct cerebellar tract only reaches from the level of the first lumbar nerve upward, chiefly

from the region of the vesicular column of Clarke ; it does not, for example, degenerate from a lesion of the lumbar enlargement. The lateral limiting layer, between the lateral pyramidal tract and posterior horn, is throughout the cord. The fibres of the antero-lateral ascending tract of Gowers, often confounded with the cerebellar tract, pass upward through the whole length of the cord. The anterior ground-fibres also extend throughout the whole length of the cord. The column of Türck is present only in the cervical and upper dorsal cord. The lateral pyramidal tract extends through the whole length of the cord.

The importance of knowing the vertical extension as well as the position of the spinal columns for practical purposes is at once evident, and in diagnosis comes out with great distinctness in localizing focal lesions of very limited extent. Such a lesion might, for example, involve only or chiefly the column of Türck, or anterior pyramidal tract, and would, therefore, give us motor-conducting symptoms, largely confined to the arms. If the lesion was lateral or peripheral, it might only or chiefly involve the ascending antero-lateral tracts, and give us for symptoms interference, with sensibility to pain and temperature, on one or both sides. The same reasoning can be readily extended to other isolated or neighboring tracts.

In considering a lesion below the upper dorsal region the practical diagnostician would not take into account the column of Türck, which has no existence below this level. The direct cerebellar column would also be out of consideration in large measure in lesions of the lumbo-sacral cord and cauda equina. On the other hand, the columns of Goll and of Burdach, the crossed pyramidal tract, the antero-lateral ascending tract, and the region of the anterior ground-fibres would be considered at any and all heights.

SEGMENTAL LOCALIZATION.

Theoretically, it is possible to localize a lesion in any segment of the cord. It is practically possible to do this in many segments of the cord, and for some the process with our present light is by no means difficult. For any vertical subdivision of the cord containing two or three segments we should be able to localize lesions with sufficient accuracy for grave operations.

In the detailed study of segmental localization, the order in which the subject will be considered is (1) sensory localization, (2) motor localization, (3) reflex localization, (4) the localization of vaso-motor and trophic phenomena. Regarding the cord as made up of a series of reflex systems, or reflex nerve-roots or arcs, as they are commonly called, sensory impressions are conveyed inward from the peripheral end organs to sensory roots and centres; thence are transferred to motor centres, and thence outward again reflexly to roots, nerves, and muscles themselves; so that the study of a single segment of the cord will include sensory, motor, and reflex phenomena. When the brain takes part the sensory impression enters the cord by the posterior nerve-roots, and, if not reflected at once, passes up the opposite side of the cord to the cerebrum, and eventually calls forth a motor impulse, which is sent down the cord to the anterior motor cells, and thence to the muscles.

SEGMENTAL SENSORY LOCALIZATION.

The sensory mechanism of the cerebrospinal system consists, then, of peripheral end organs which receive impressions, incoming nerve-fibres which carry them by way of the posterior roots into the spinal cord, commissural fibres which immediately or almost immediately transfer them to the opposite half of the cord, and ascending conducting tracts by which they are conveyed up the cord to

the oblongata, pons, crus, internal capsule, corona radiata, and brain cortex. Various interrupting ganglia are interposed along this sensory highway ; but these we shall not here consider. Dividing one-half of the spinal cord will cause anæsthesia in the opposite half of the body below the place of hemisection, and at the same time a line or belt of hyperæsthesia or anæsthesia may be produced on the same side as the lesion in the distribution of some particular nerve-root or roots injured. This has already been referred to in considering spinal hemiplegia and hemiparaplegia. This anæsthesia is in the main caused by severance of the ascending conducting paths for sensation, which are in the side of the cord opposite to the parts of the body supplied. It is necessary, however, to consider more particularly the sensory effects in certain territories and their special subdivisions, because of the implication of one or more segments, or limited vertical extensions, of the spinal cord.

Segmental sensory localization has not been much elucidated by the contributions of physiologists, who have done so much for motor localization. The contributions to segmental sensory localization are, indeed, few and of quite recent date. The most valuable—some of them already referred to in a general way—have been furnished by Ross* and Thorburn ;† and by Herringham,‡ Paterson,§ and Goodsir,‖ who are quoted by Ross. The limits

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* *Brain*, April, 1884; ibid., January, 1885; ibid., January, 1888.

† *Brain*, January, 1887; ibid., January, 1888; ibid., October, 1888; *Brit. Med. Jour.*, December 22, 1888; and *Med. Chron.*, April, 1889.

‡ *Proc. Roy. Soc.*, vol. xli., 1887.

§ *Jour. Anat. and Phys.*, April, 1887; ibid., July, 1887; and *Quart. Jour. Micr. Sci.*, vol. xxviii., 1887.

‖ *Edin. New Phil. Jour.*, N. S., vol. v., January, 1887; and *Anat. Mem.*, vol. ii. Quoted from Paterson by Ross.

of this paper will allow me only to refer briefly to this subject, chiefly giving the facts determined by Ross and Thorburn. Heiberg's* "Atlas" was of value in my studies of the various sensory areas of the skin. The papers from which the most useful data have been obtained have been clinico-pathological and embryological,—studies of cases of injury to the spinal cord, intraspinal nerve-trunks, and extraspinal nerve-trunks and plexuses; and investigations chiefly developmental and morphological of the limb plexuses of the lower animals and of man.

A spinal nerve, as Ross shows, is derived from the cord by a posterior (superior) gangliated and an anterior (inferior) non-gangliated root. Where the two roots come together the nerve divides into a superior primary division supplying the skin of the back over the neural canal; and an inferior primary division, which subdivides into a dorsal trunk, supplying the lateral, and a ventral supplying the ventral or anterior surfaces. A branch is also given off the viscera.

The entire surface of the body may be divided into three great nerve-territories,—one posterior, one lateral, and one anterior or ventral.

The sensory nerve-supply to the posterior territory is comparatively easy to understand. It is from the superior primary divisions of the spinal nerves. It occupies a region which may be roughly described as consisting of the back of the head and the back,—the region over the neural canal. Heiberg says that its lower limit may be taken to be roughly indicated by the crest of the ilium inside of the sacrum. The back of the head is supplied from the upper cervical nerves, because in

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* "Atlas of the Cutaneous Nerve-Supply of the Human Body." By Jacob Heiberg, M.D. Illustrated by Alfred Fosterud. Translated and edited by W. W. Wagstaffe, B.A., F.R.C.S.

the process of evolution the skin of the back of the neck has been dragged upward in order to cover the greatly-enlarged brain and skull of the man. This posterior nerve-territory in the head reaches forward over the top of the head and forehead to the root of the nose, its anterior portion being supplied from the superior primary or first division of the trigeminal or fifth nerve. Ross compares the distribution of the sensory nerves in the dorsal or posterior region of the cord with that which is seen in the lowest vertebratæ,—the amphioxus, for example. In the amphioxus, section of the posterior roots of a pair of nerves will cause anæsthesia of exactly corresponding sections of the body. In man, section of the dorsal posterior roots, superior primary division, likewise produces anæsthesia of the skin of corresponding segments of the body, the only differences being that in man some anastomoses of different dorsal nerves occur, and the nerve areas of distribution tend to be placed successively lower with reference to the levels at which the nerves originate.

The anterior nerve-territory of the trunk in a manner corresponds to the posterior territory,—that is, it occupies a position on the front of the trunk and face comparable in extent to that of the posterior territory on the back and head. The anterior and lateral cutaneous nerves of the thorax are branches from the same nerves. The lateral territory is the largest and in many respects the most important sensory surface. Heiberg says that the line of demarcation between the lateral and anterior territories generally divides the breast into two equal halves, the distribution of the anterior branches, however, extending on to the front of the thighs. The extremities are largely supplied by the lateral branches. In the neck the branches are all anterior and posterior; in the thorax the anterior and lateral cutaneous branches are from the same nerves.

The limb plexuses are formed from the union of the branches of the inferior primary divisions of the nerves. The sensory nerves from the two branches of this inferior primary division are very irregularly distributed in the limbs,—that is, looking at the matter from a gross topographical point of view. This is due to the fact that, in the process of development of the limbs in the evolution of higher from lower animal forms, the sensory nerves, both dorsal and ventral, have been irregularly arrested in the extremities. In the formation of the plexuses the dorsal branches nearly always unite with the dorsal, and the ventral with the ventral branches only ; although Paterson, according to Ross, admits exceptions in the case of the small sciatic nerve, which is formed by a union of dorsal and ventral fibres, and in that of the external and short saphenous nerves which are undoubtedly so constituted.

In the limbs, then, the sensory disturbances which are due to involvement either of the cervical or lumbo-sacral segments of the spinal cord, or of the nerve-roots or nerves springing from these segments, are distributed more or less longitudinally in accordance with the particular segment or nerve affected. The hyperæsthesia, for example, which in a dorsal lesion extends around the trunk in the form of a belt or girdle, in a cervical or lumbosacral lesion has a longitudinal distribution more or less regular in the limbs. In like manner, the anæsthesia and paræsthesia present in the limbs have distributions in accordance with the shape of the cutaneous sensory areas. A knowledge of sensory segmental localization is therefore necessary that the diagnostician shall quickly be able to decide on the spinal or other localization of a lesion by the zone of disturbance in the limb.

Sensory segmental localization follows certain laws. If the upper extremity, according to Ross, be placed in the embryological posi-

tion,—that is, with the thumb directed outward and upward, the palm forward,—the preaxial border from the tip of the shoulder down to the metacarpo-phalangeal articulations of the index-finger and thumb is supplied by the fifth cervical root, and the postaxial border, from the axilla to the finger-tips inclusive, is supplied by the humeral branch of the second, the first dorsal, and the eighth cervical nerves. Observations made in cases of disease of the cauda equina have also convinced Dr. Ross that, if the lower extremities be also placed in the embryological or tailor position, the preaxial border is supplied by the cutaneous nerves of the four upper lumbar nerves, and the postaxial by the coccygeal and sacral sensory nerves. He has concluded also that the most distal parts of the preaxial border were supplied from the lower of the four lumbar nerves, and of the postaxial border by the higher sacral nerves.

The chief law of sensory distribution, as worked out by Herringham and adopted by Ross, is as follows:

"A. Of two spots on the skin, that which is nearer the preaxial border tends to be supplied by the higher nerve.

"B. Of two spots in the preaxial area, the lower tends to be supplied by the lower nerve; and of two spots in the postaxial area, the lower tends to be supplied by the higher nerve."

While many cases of disease limited to the anterior horns or to particular cell-groups of these horns have been recorded, I do not know of any reports of lesions circumscribed in the posterior horns of particular segments of the cord. Most of our practical knowledge of sensory segmental localization is therefore to be derived from cases which have been reported by Ross, Thorburn, and others, in which both the cord and nerve-roots have been injured extensively. To the papers of these observers I will refer those interested

for details, giving here only some of the summarized conclusions.

Thorburn,* for example, in one of his papers on spinal localization as indicated by spinal injuries, speaks as follows with reference to the distribution of anæsthesia in the upper limbs: "Dr. Ross has fully demonstrated the distribution of the sensory nerves in the upper limb. Regarding the limb in its embryological position, we find that it is projected as a bud from the trunk, the hand being supine and the radius upward, so that the palmar surface is anterior. In this position the bud carries out with it branches of the anterior primary divisions of the spinal segmental nerves from the fifth cervical to the first dorsal, inclusive; and as these nerves maintain in the adult their embryological relations, we have the several roots supplying the limbs in numerical order from the radial to the ulnar side. Hence, then, the higher the paralysis extends in the cord through the brachial region, the farther will the anæsthesia extend from the ulnar towards the radial side. This arrangement is fully demonstrated by our cases. It is necessary to refer again to the distribution which will be obvious to any one who takes the trouble to read the reports, and of which I have already spoken in my previous paper. It will be found that the fifth root supplies the region overlying the deltoid muscle, and the outer aspect of the arm and forearm as far as the styloid process of the radius or base of the thumb, and that the eighth cervical and first dorsal supply the little finger and inner side of the hand, forearm, and arm, the remaining roots providing for the central parts of the limb on both anterior and posterior aspects. It will, however, be found that these central roots supply relatively a much less extensive area than those above and below them."

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* *Brain*, October, 1888.

In his paper on injuries to the lumbo-sacral region,* Thorburn likewise summarizes the sensory distribution of the various lumbo-sacral nerve-roots. This summary is as follows:

"First lumbar nerve: ilio-hypogastric and ilio-inguinal.

"Second lumbar nerve: outer (?) and upper part of thigh.

"Third lumbar nerve: anterior aspect of thigh below second lumbar.

"Fourth lumbar nerve: anterior part of leg.

"Fifth lumbar nerve: Back of thigh, except in distribution of first, second, and third sacral.

"First sacral nerve: a narrow strip on back of thigh; back of leg and ankle; sole; part of dorsum of foot.

"Second and third sacral nerves: perineum, external genitals, 'saddle-shaped' area of back of thigh."

MOTOR LOCALIZATION.

Methods, anatomical, physiological, microscopical, clinico-pathological, and clinical, have all contributed their share to our knowledge of motor localization; and to some of the results obtained in each of these ways I will briefly refer.

ANATOMICAL RESEARCHES.

Herringham carefully and patiently dissected the nerves of the brachial plexus on many subjects, fœtal and older, in order to trace these nerves to their final destinations in the muscles and the skin. He gives a tabular statement showing the usual nerve-supply of muscles of the upper limbs, as follows:

"Third, fourth, and fifth cervical: levator anguli scapulæ.

"Fifth cervical: rhomboids.

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* *Med. Chronicle*, April, 1889.

"Fifth, or fifth and sixth cervical: supra spinatus, infraspinatus, teres minor.

"Fifth and sixth cervical: subscapularis, deltoid, biceps, brachialis anticus.

"Sixth cervical: teres major, pronator teres, flexor carpi radialis, supinator longus and brevis, superficial thenar muscles.

"Fifth, sixth, and seventh cervical: serratus magnus.

"Sixth and seventh cervical: extensor carpi radialis.

"Seventh cervical: coraco-brachialis, latissimus dorsi, extensors at back of forearm, outer head of triceps.

"Seventh and eighth cervical: inner head of triceps.

"Seventh, eighth, and ninth cervical: flexor sublimis, flexor profundis, carpi ulnaris, longus pollicis, and pronator quadratus.

"Eighth cervical: long head of triceps, hypothenar muscles, interossei, deep thenar muscles."

PHYSIOLOGICAL RESEARCHES.

Few experimental investigations with reference to the exact functions of the nerve-roots and horns of the spinal cord have been made. One of the most important and earliest of these researches was that of Ferrier and Yeo in 1880.* These investigations were as to the effects of irritation of the motor roots of the brachial and crural plexuses of monkeys. The faradic current was employed. It was found that each motor root represented a distinct functional combination. The muscles set in action were so related as to bring about a definite action of an adapted nature. The muscles affected by electricity exciting any one root were related in function. The relation was not simply one of contact or nearness.

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* *Proc. Roy. Soc.*, London, No. 212.

The actions produced by the different roots were summarized by Ferrier as follows:

"First dorsal: action of the intrinsic muscles of the hand, muscles of the ball of the thumb, interossei, etc.

"Eighth cervical: closure of the fist, with pronation and ulnar flexion of the wrist, retraction of the arm, with extension of the forearm.

"Seventh cervical: the *scalptor ani* action, —viz., adduction with rotation inward and retraction of upper arm, extension of forearm and flexion of wrist and fingers, so as to bring the tips against the flank.

"Sixth cervical: the movement of 'attention,'—viz., adduction and retraction of upper arm, extension of forearm, pronation and flexion of wrist, the palm of the hand being brought towards pubes.

"Fifth cervical: movement of the hand towards the mouth,—viz., raising the upper arm inward, flexion of the forearm with supination, and extension of the wrist and fingers.

"Fourth cervical: a similar movement of forearm and hand,—viz., the upper arm is raised upward and backward."

The actions of the *lower extremity* were respectively:

"Second sacral: action of the intrinsic muscles of the foot,—viz., adduction and flexion of the hallux, with flexion of the proximal phalanges and extension of the distal.

"First sacral: flexion of the leg, plantar flexion of the foot, flexion of all the toes at the proximal phalanges, and also of the distal phalanx of the hallux.

"Fifth lumbar: outward rotation of the thigh, flexion and inward rotation of the leg, plantar flexion of the foot, and flexion of the distal phalanges.

"Fourth lumbar: extension of the thigh, extension of the leg, and pointing of the great toe.

"Third lumbar: flexion of the thigh and extension of the leg."

Paul Bert and Marcacci,* in 1881, studied the distribution of the motor roots of the lumbar plexus, their researches being made on dogs and cats. The nerves were very carefully cut close to their origin, and stimulated electrically with the utmost care. "It was found that the first root of the lumbar plexus determines the contraction of the sartorius, the rectus, and the psoas muscles, which are closely connected in the dog and cat, and all of which flex the hip upon the trunk. The second root of the plexus excites contraction in the anterior portion of the vastus externus, a part of the tensor of the fascia lata, and the vastus internus,—*i.e.*, in the muscles which extend the leg on the thigh. The function of the third root is similar to that of the second, with some differences in detail. It excites part of the vastus internus, the anterior part only of the biceps, which is an extensor, while the posterior portion is a flexor. The fourth root causes movements in the posterior part of the biceps, the semi-tendinosus and the semi-membranosus (flexors of the leg and thigh), and the second and third adductors of the thigh, and the extensors of the thigh. It thus innervates three kinds of movements, which are in no respect opposed or contradictory. The fifth root presides over the movements of the tail. From these results the experimenters conclude that there is evidently a systematic arrangement of the innervation of the limb at the origin of the nerves of the spinal cord; it is a functional systematization,—*i.e.*, the motor filaments arising at a given level are distributed to muscular masses, which act together, and concur to produce an associated movement. In the second place (as Duchenne

* The results obtained by Bert and Marcacci were summarized in the *Lancet* for October 1, 1881.

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long ago demonstrated and as is now generally recognized), the anatomical unity of a muscle has no physiological correspondence. A single muscular mass may be in one part a flexor, in another an extensor. But the nerve distribution corresponds to the function, in so far as the different roots, innervating the several functions, are concerned."

Other researches, which are referred to by Ferrier and Yeo, have been made on the lower animals with a view to determine the situations of the roots of the plexuses of the limbs. Peyer and Krouse found that most of the muscles of the limbs were supplied by more than one root of the plexus. It was determined, among other things, that the muscles nearer the shoulder were supplied by the higher roots and those of the hand by the lower roots of the plexus; also that the sensory roots have a corresponding distribution to the distribution of the anterior roots.

During the operation by Dr. Abbe* on Dr. Dana's case of intractable brachial neuralgia, several interesting experiments were made with the faradic battery, so far as I know the first of the kind on man. With a sponge electrode on the back, a metal-point electrode was applied at various points. When applied to the sixth nerve, just external to the dura, it caused contraction of the supra- and infra-spinati, rhomboid, latissimus dorsi, pectoralis major, teres, and deltoid. Application to the seventh nerve caused contraction of the pectoral, latissimus dorsi, and abductors of the arm; to the eighth nerve, similar contraction and pain.

MICROSCOPICAL INVESTIGATIONS: CELL-GROUPS WHICH REPRESENT PHYSIOLOGICAL UNITS IN THE HORNS OF THE SPINAL CORD.

Microscopical investigations show that in cross sections of the spinal cord a distinct

* *Medical Record*, February 9, 1889.

transverse localization of cell-groups which are related to certain definite muscles or muscular groups concerned in particular movements may be readily determined. The cord is not only an organ composed of a series of segments placed one above the other, but these segments differ in size both vertically and horizontally. The gray matter particularly shows marked differences in shape and size in various transverse sections. These differences depend largely upon the number and grouping of the cells.

Starr, drawing from various investigations, details at length the manner in which in the anterior horns of the cord the cells are arranged in distinct groups which can be determined and enumerated from within outward. He gives a series of diagrams which show the manner not only in which these cells are arranged in clusters at certain levels of the cord, but also how these continue or fail to continue in a vertical direction from one level to another.

These cell-clusters differ in number and in relative position at various heights in the cord. In the second cervical segment, for example, are three, two continuing downward into the third segment of the cord, the third even into the fourth segment. In the fourth cervical segment the number of groups is five. Again, in the fourth lumbar segment and below this as far as the sacral three groups are present. These groupings in the cord are enumerated and described by Starr and also by Gowers and Ross. The only point for us to remember in connection with practical localization is that each of these groups is probably a physiological unit. They are spinal centres of function comparable to the cerebral centres of motor function. Spitzka, in 1880, first advanced this opinion :

" The nearer the muscle is to the ventral aspect of an animal," he said, "the nearer will its nucleus be to the median line of the

cord; and the nearer the muscle is to the dorsal aspect of the animal, the nearer will its nucleus be to the lateral cornu of the cord. Flexor nuclei are therefore in internal, extensor nuclei in external and posterior cell-groups. Thus the cell-group in the apex of the anterior horn as well as in the lateral cornu is fairly developed in the dorsal region, while the portion of the gray substance situated internally is deficient in cells, in evident relation to the deficiency of prevertebral muscles. To the extremities of the body, lateral extension of the cornua correspond, and in these the same relative position of flexor and extensor nuclei is probable. As is shown in the enlargements, there is much more differentiation of the cell-groups in such extensions in the multidigitate animals than in the solipeds, as is shown by comparing the cord of man with that of the horse. Whether groups of muscles be flexor or extensor, it will be found that the nearer they are to the animal axis, the nearer will their nuclei be to the central canal. This is especially true of the flexor nuclei. The increasing development of a cell-group in the upper cervical region near the central canal in animals with powerful head and neck flexors seems to support this statement. Extensors remote from the axis, such as the trapezius, have their nuclei quite remote from the central canal." (Quoted by Starr.)

The diagnosis of a spinal lesion in the horns or columns of the cord may sometimes be at least of negative importance in deciding the question of operation. This was illustrated in the case of Lloyd and Deaver, of a cyst or extravasation of the cervical region of the cord. The lesion in this case was found to be a hemorrhagic extravasation in the anterior horns of the cord, practically out of reach of the knife. In this case, however, an external swelling which made operation important was present. If the external indi-

cations had not been present, the close diagnosis of the exact location of the lesion in a transverse section of the cord would have been of great importance. We have now data on hand for such localization at different levels. We can even make a fairly exact diagnosis of the position of a lesion at various positions from within outward in the anterior horns of the cord.

It may even be found that our knowledge of the exact position from without inward of these groups of cells which represent physiological units — which are, in other words, related to certain definite movements—may occasionally prove of practical value. Decision as to operating, for example, may depend not only upon our knowledge of the exact level and vertical limitations of a lesion, but also to some extent upon the amount of compression and of destruction by invasion of the spinal cord. As has just been stated, the nuclei of extensor muscles are situated in external and posterior cell-groups, while those of flexor nuclei are more internal ; therefore, the predominance of extensor or of flexor paralysis may help sometimes to a conclusion as to the amount of transverse damage of the cord.

CLINICO-PATHOLOGICAL AND CLINICAL INVESTIGATIONS.

As already stated, Thorburn has published certain clinical and pathological observations upon injuries to the cervical region of the spinal cord, and has endeavored to draw therefrom an accurate picture of the functions of each of the nerve-roots entering into the formation of the brachial plexus. His usual method consisted in noting accurately the distribution of the paralysis and anæsthesia which ensued immediately upon a lesion of the cord, of which the exact site had been determined by post-mortem examination ; also

of pursuing the changes which resulted from the consequent ascending myelitis. He has also applied the same methods to the lumbo-sacral or crural plexus.

He has tabulated provisionally, as follows, what he is led, from the evidences of his cases, to believe to be the arrangement, from above downward, of the muscle nuclei in the cervical cord :

" Fourth cervical nerve : supraspinatus and infraspinatus, teres minor (?).

" Fifth cervical : biceps, brachialis anticus, deltoid, supinator longus, supinator brevis (?).

" Sixth cervical : subscapularis, pronators, teres major, latissimus dorsi, pectoralis major, triceps, serratus magnus.

" Seventh cervical : extensors of the wrist.

" Eighth cervical : flexors of the wrist.

" First dorsal nerve : interossei, other intrinsic muscles of the hand."

He has likewise summarized for the lumbo-sacral region of the spinal cord the arrangement of both the motor and sensory fibres of the nerve-roots. His summary, he states, is to be distinctly understood as only that for which his own cases gave evidence,—that is, they are positive evidence for the facts reported, but do not negative the existence of other facts the existence of which was not proved by the cases. Thus, for example, although no doubt the second lumbar root affords muscular branches, these are ignored because his cases yield no evidence of the same. His summary of the sensory arrangement has already been given. The following is the motor distribution as determined by him:

" First lumbar nerve : none.

" Second lumbar : none.

" Third lumbar : sartorius, adductors of thigh, flexors of thigh.

" Fourth lumbar : extensors of knee, abductors of thigh.

" Fifth lumbar : hamstring muscles.

" First and second sacral : calf muscles,

glutei, peronei, extensors of ankles, intrinsic muscles of foot.

"Third sacral: perineal muscles (erector penis, transversalis perinei, accelerator urinæ, etc.).

"Fourth sacral: bladder and rectum."

Ferrier,* in a paper on atrophic spinal paralyses, has applied the facts determined by his and other experiments, and made a provisional enumeration, as a guide to further more minute clinical research, of the muscles which are likely to be affected in poliomyelitis limited to each segment, the muscles being placed in the order in which they would probably suffer.

"First dorsal type: the intrinsic muscles of the hand,—viz., muscles of the thenar and hypothenar eminences and interossei.

"Eighth cervical type: long flexors, ulnar flexors of wrist, intrinsic muscles of hand, extensors of wrist and phalanges, long head of triceps (pectoralis major?).

"Seventh cervical type: teres major, latissimus dorsi, subscapularis, pectoralis major, flexors of wrist and fingers (median), triceps.

"Sixth cervical type: latissimus dorsi, pectoralis major, serratus magnus, pronators (flexor of wrist?) triceps.

"Fifth cervical type: deltoid (clavicular portion), biceps, brachialis anticus, serratus magnus, supinator longus, extensors of wrist and fingers.

"Fourth cervical type: deltoid, rhomboid, supra- and infraspinatus (teres major), biceps, brachialis anticus, supinator longus, extensors of wrist and fingers, diaphragm."

In the lower extremity:

"Second sacral type: intrinsic muscles of the foot, strictly parallel to the first dorsal type.

"First sacral type: muscles of calf (plantar flexors), hamstrings, long flexor of big toe, intrinsic muscles of foot.

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* *Brain*, vol. iv. p. 226, 1881–1882.

"Fifth lumbar type: flexors and extensors of toes, tibial muscles, sural muscles, peroneal muscles, outward rotators of the thigh, hamstrings.

"Fourth lumbar type: extensors of thigh, extensor cruris, peroneus longus, adductors.

"Third lumbar type: ilio-psoas, sartorius, adductors, extensor cruris."

On the principles of localization certain types of spinal paralysis have also been determined and named by others, as by Remak and Erb. Remak speaks of an upper-arm type of atrophic spinal paralysis, in which are jointly affected the supinator longus with the brachialis anticus and the biceps and the deltoid. The same author describes the forearm type in which the extensors of the wrist and fingers, and the muscles of the hand are paralyzed. He has also described three types of paralysis of the lower extremities,—"The first in which the extensors and adductors of the leg are affected together, the sartorius muscle, however, escaping, although it is supplied by the anterior crural nerve, which also supplies the extensors; a second type, in which the ilio-psoas, sartorius, and flexors of the leg are affected together; and a third type, in which the muscles upon the leg and foot are involved with the exception of the tibialis anticus. He notices that the last-named muscle is rarely paralyzed with the other muscles, and that when it is affected, the other muscles moving the foot frequently escape." (Starr.)

SEGMENTAL LOCALIZATION OF REFLEX CENTRES.

Certain cells in the gray matter of the spinal cord preside over reflex action. These reflex actions, and the areas in which they are capable of being excited, are described in the more recent text-books. These centres are

cutaneous or superficial, and muscular (or musculo-tendinous) or deep. The centres for these various reflexes are enumerated by Gowers as follows:

"Superficial reflex action: plantar, second sacral; gluteal, fourth lumbar; cremaster, second lumbar; abdominal, sixth to eleventh dorsal (epigastric, sixth dorsal); scapular, fifth cervical to first dorsal.

"Muscle reflex action: calf muscles (foot clonus), fifth lumbar and first sacral; knee-jerk, third and fourth lumbar; flexor digitorum, triceps, seventh cervical; biceps, supinator longus, sixth cervical."

An important set of reflex centres for localization purposes are those which preside over various actions more or less complex and involuntary. These include such as the following: Cilio-spinal, cremasteric, sexual, parturitional, vesical, and anal. Starr enumerates the position of these centres as follows: Cremasteric, first to third lumbar; vesical, third lumbar; rectal or anal, fourth lumbar. By other observers the cilio-spinal centre is placed in the lower cervical cord and dorsal, as far as the second or third dorsal vertebra. The sexual, or erection centre, has been placed without close localization in the lumbar cord, probably about the second or third lumbar segment. Korner has located what he terms the parturition centre at the level of the first or second lumbar vertebra. Those centres for complex reflexes which are really valuable for purposes of practical localization are the cilio-spinal, cremasteric, vesical, and anal centres; their position will be indicated in table at the conclusion of this article. The latest investigations of Thorburn and others indicate that the centres for the bladder and the anus or rectum are in the extreme lower part of the cord; in fact, in the terminal portion of the cord, the region of the third, fourth, and fifth sacral and the coccygeal nerve-roots.

VASO-MOTOR AND TROPHIC LOCALIZATION.

Vaso-motor and trophic centres are distributed throughout the entire vertical extent of the spinal cord. Those connected with the muscles are identical with, or situated close by, the corresponding motor nuclei in the anterior horns. Vaso-motor and trophic centres for the skin, nails, and joints also have a local habitation in the spinal cord. Pathological facts, as those, for instance, which have been obtained in studying syringomyelia, point to the central gray matter of the cord as the probable seat of these centres. By the central gray matter I mean here that which is situated around or near the central canal. In the posterior portion of this central gray matter it is probable that the vaso-motor and trophic centres for the skin, nails, and joints are situated, while more anteriorly are probably placed the trophic centres for the bones. A special collection of large bipolar cells is found in the postero-internal gray matter, and extends in the form of a continuous column from about the seventh cervical to the second or third lumbar segment. This collection of cells, first described by Lockhart Clarke, is usually designated as Clarke's vesicular column, and has been referred to several times in this paper. It is now almost established by various pathological reports, and the careful anatomical and microscopical investigations of Gaskell, that this column represents a series of vaso-motor and visceral centres. Communicating nerves have been traced to and from this vesicular column to the ganglia and fibres of the so-called sympathetic nervous system. When, therefore, vaso-motor and trophic phenomena are present these regions of the central gray matter must be considered.

In 1884,* and again in 1888,† Starr summarized in tabular form the functions of the

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* *Am. Jour. Neurol. and Psych.*

† *Am. Jour. Med. Sci.*, May, 1888.

various segments of the spinal cord. His last table represents fairly well the status of spinal localization. In concluding this article I will give this table of Starr, with modifications based upon the results obtained by Herringham, Ross, Thorburn, and others. A study of this table, and of the various summarized statements which have already been given, will enable the diagnostician with approximate accuracy to localize the height of a lesion affecting the segments of the cord or the spinal nerve-roots. In the column for sensation the cutaneous nerves are given in parentheses. This list is not complete, but it is hoped that it will be of assistance in sensory localization.

LOCALIZATION OF THE FUNCTIONS OF THE SEGMENTS OF THE SPINAL CORD.

Segment.	Muscles.	Reflex.	Sensation.
Second and third cervical.	Sterno-mastoid. Trapezius. Scaleni and neck. Diaphragm.	*Hypochondrium*(?) Sudden inspiration produced by sudden pressure beneath the lower border of ribs.	Back of head to vertex and neck. (Occipitalis major, occipitalis minor, auricularis magnus, superficialis colli, and supraclavicular.)
Fourth cervical.	Diaphragm. Deltoid. Biceps. Coraco-brachialis. Supinator longus. Rhomboid. Supra- and infraspinatus.	*Pupillary* (fourth cervical to second dorsal). Dilatation of the pupil produced by irritation of neck.	Neck. Shoulder, anterior surface. Outer arm. (Supraclavicular, circumflex, external (musculo-cutaneous) cutaneous.)
Fifth cervical.	Deltoid. Biceps. Coraco-brachialis. Brachialis anticus. Supinator longus. Supinator brevis. Deep muscles of shoulder-blade. Rhomboid. Teres minor. Pectoralis (clavicular part). Serratus magnus.	*Scapular* (fifth cervical to first dorsal). Irritation of skin over the scapula produces contraction of scapular muscles. *Supinator longus.* Tapping the tendon of the supinator longus produces flexion of forearm.	Back of shoulder and arm. Outerside of arm and forearm to the wrist. (Supraclavicular, circumflex, external cutaneous, internal cutaneous, posterior spinal branches.)

Segment.	Muscles.	Reflex.	Sensation.
Sixth cervical.	Biceps. Brachialis anticus. Subscapular. Pectoralis (clavicular part). Serratus magnus. Triceps. Extensors of wrist and fingers. Pronators.	*Triceps* (fifth to sixth cervical). Tapping elbow tendon produces extension of forearm. *Posterior wrist* (sixth to eighth cervical). Tapping tendons causes extension of hand.	Outer side and front of forearm. Back of hand, radial distribution. (Chiefly external cutaneous, internal cutaneous, radial.)
Seventh cervical.	Triceps (long head). Extensors of wrist and fingers. Pronators of wrist. Flexors of wrist. Subscapular. Pectoralis (costal part). Serratus magnus. Latissimus dorsi. Teres major.	*Anterior wrist* (seventh to eighth cervical). Tapping anterior tendons causes flexion of wrist. *Palmar* (seventh cervical to first dorsal). Stroking palm causes closure of fingers.	Radial distribution in the hand. Median distribution in the palm, thumb, index-, and one-half middle finger. (External cutaneous, internal cutaneous, radial, median, posterior spinal branches.)
Eighth cervical.	Triceps (long head). Flexors of wrist and fingers. Intrinsic hand muscles.	....	Ulnar area of hand, back, and palm, inner border of forearm. (Internal cutaneous, ulnar.)
First dorsal.	Extensors of thumb. Intrinsic hand muscles. Thenar and hypothenar muscles.	....	Chiefly inner side of forearm and arm to near the axilla. (Chiefly internal cutaneous and nerve of Wrisberg or lesser internal cutaneous.)
Second dorsal.	....	....	Inner side of arm near and in axilla. (Intercosto-humeral.)
Second to twelfth dorsal.	Muscles of back and abdomen. Erectores spinæ.	*Epigastric* (fourth to seventh dorsal). Tickling mammary region causes retraction of the epigastrium. *Abdominal* (seventh to eleventh dorsal). Stroking side of abdomen causes retraction of belly.	Skin of chest and abdomen, in bands running around and downward, corresponding to spinal nerves. Upper gluteal region. (Intercostals and dorsal posterior nerves.)

Segment.	Muscles.	Reflex.	Sensation.
First lumbar.	Ilio-psoas. Rectus. Sartorius.	*Cremasteric* (first to third lumbar). Stroking inner thigh causes retraction of scrotum.	Skin over groin and front of scrotum. (Ilio-hypogastric, ilio-inguinal.)
Second lumbar.	Ilio-psoas. Sartorius. Quadriceps femoris.	*Patellar*. Striking patellar tendon causes extension of leg.	Outer side of thigh. (Genito-crural, external cutaneous.)
Third lumbar.	Quadriceps femoris. Anterior part of biceps. Inner rotators of thigh. Abductors of thigh.	....	Front of thigh. (Middle cutaneous, internal cutaneous, long saphenous, obturator.)
Fourth lumbar.	Abductors of thigh. Adductors of thigh. Flexors of knee. Tibialis anticus. Peroneus longus.	*Gluteal* (fourth to fifth lumbar). Stroking buttock causes dimpling in fold of buttock.	Inner side of thigh, leg, and foot. (Internal cutaneous, long saphenous, obturator.)
Fifth lumbar.	Outward rotators. Flexors of knee. Flexors of ankle Peronei. Extensors of toes.	*Achilles tendon.* Over-extension causes rapid flexion of ankle, called ankle clonus.	Back and outer side of leg and ankle; sole; dorsum of foot. (External popliteal, external saphenous, musculo-cutaneous, plantar.)
First and second sacral.	Flexors of ankle Extensors of ankle. Long flexor of toes. Intrinsic foot muscles.	*Plantar* (fifth lumbar to second sacral). Tickling sole of foot causes flexion of toes and retraction of leg.	Back and outer side of leg and ankle; sole; dorsum of foot. (Same as fifth lumbar.)
Third, fourth, and fifth sacral.	Perineal. Muscles of bladder, rectum, and external genitals.	Vesical centres. Anal centres.	Back of thigh, anus, perineum, external genitals. (Small sciatic, pudic, inferior hemorrhoidal, inferior pudendal.)
Fifth sacral and coccygeal.	Coccygeus muscle.	....	Skin about the anus and coccyx. (Coccygeal.)